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A Look at Very Small Aperture Terminal Satellite Networks

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16. Abstract
One candidate technology for bypass is very small aperture terminal (VSAT) satellite communications. This technology uses small, inexpensive earth stations to replace lensed dedicated circuits. This report provides a brief overview of VSAT technology, and discusses some issues to be considered when implementing a VSAT network.

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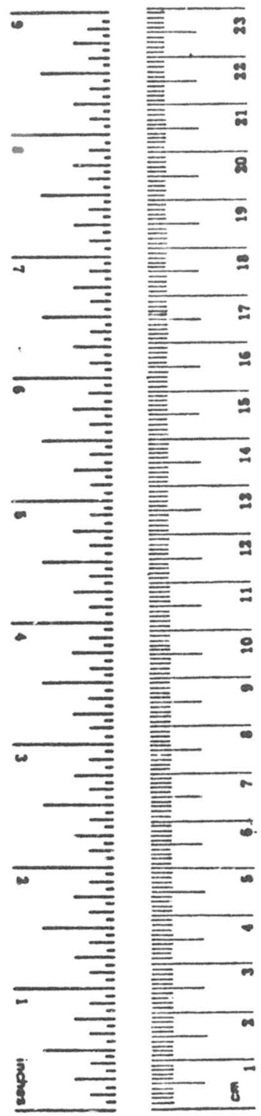
NOTICE

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

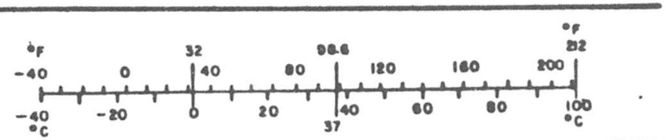
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



A LOOK AT VERY SMALL APERTURE TERMINAL SATELLITE NETWORKS

Introduction

The break-up of AT&T has had a profound impact on the world of telecommunications. Among the major changes is the way leased circuits are priced. When AT&T "ruled the world," long-haul circuits were high cost, and some of that cost subsidized local circuits. Local loops to the central office were usually a fixed cost, regardless of length.

With the divestiture of the Bell operating companies by AT&T, some long haul circuits (inter-LATA) prices have come down while local loops (intra-LATA) are now priced at their cost. This cost is distance sensitive, and in many cases, higher that the old fixed rates. The result is a new market for bypassing the local telephone company and the common carriers.

One option for bypass is very small aperture terminal (VSAT) satellite systems. This report will provide an overview of this technology, its advantages, disadvantages, and discuss issues that should be considered in the procurement and implementation of a VSAT system.

1.0 What is VSAT?

A discussion of of VSAT should begin with a brief review of satellite communications principles. Satellite communications are accomplished by transmitting a signal from an earth station to satellite, and having the satellite retransmit that same signal to another earth station. These earth stations may be fixed (stationary) or mobile. Mobile earth stations can be carried aboard vessels, airplanes, vehicles, or carried by people. Fixed earth stations vary from large (30 meter and up) antenna sizes to very small (1 meter or less), depending upon the application. In most cases, much of the complexity of the system is built into the earth station, to simplify the tasks of the satellite.

The satellite, often referred to as the space segment of the system, is little more than a repeater. Most communications satellites today are located in an orbit 22,500 miles above the equator. This orbit makes them appear geo-stationary, i.e., their position relative to the earth does not change. The advantages to this are that the coverage area of the satellite remains constant and predictable, and that narrow beam antennas can be used at earth stations without continuous re-pointing of the antenna. Figure 1 shows one example of a typical satellite system configuration.

Although satellite communications are possible at most frequencies, practical considerations dictate the use of frequencies in the UHF range or higher. Many commercial satellite systems operate in C-band (4-6 GHz) and Ku-band (12-14 GHz).

The Development of VSAT

Until recently, satellite communications required large terminals and large antennas. The primary market for these systems was moving wide bandwidths over long distances. This required high powered earth stations to achieve the signal-to-noise ratio needed for accurate transmission. Typical uses were long distance transmission of television, telephone calls, and high volume data transmission services.

There are two ways to reduce the size of a ground station transmit antenna: (1) increase transmitter power, or (2) reduce the data rate. The VSAT market is the result of some technological advances and creative thinking. Technology has permitted higher power devices to be made smaller, reducing the overall size of the terminal. With a higher power transmitter, antenna size can be reduced to achieve the same effective radiated power. A smaller antenna permits much more flexibility in installation. Building owners will not permit 10-20 meter antennas, but may permit installation of 1-2 meter antennas.

The creative thinking was a re-examination of the potential uses of satellite communications. Not everyone has a need for high data rate, high volume communications. If the data rate is slowed down, less power is required to achieve the same bit error rate (BER). If less power is necessary, smaller terminals can be used. Through the combination of technology and this re-examination, the VSAT market was born.

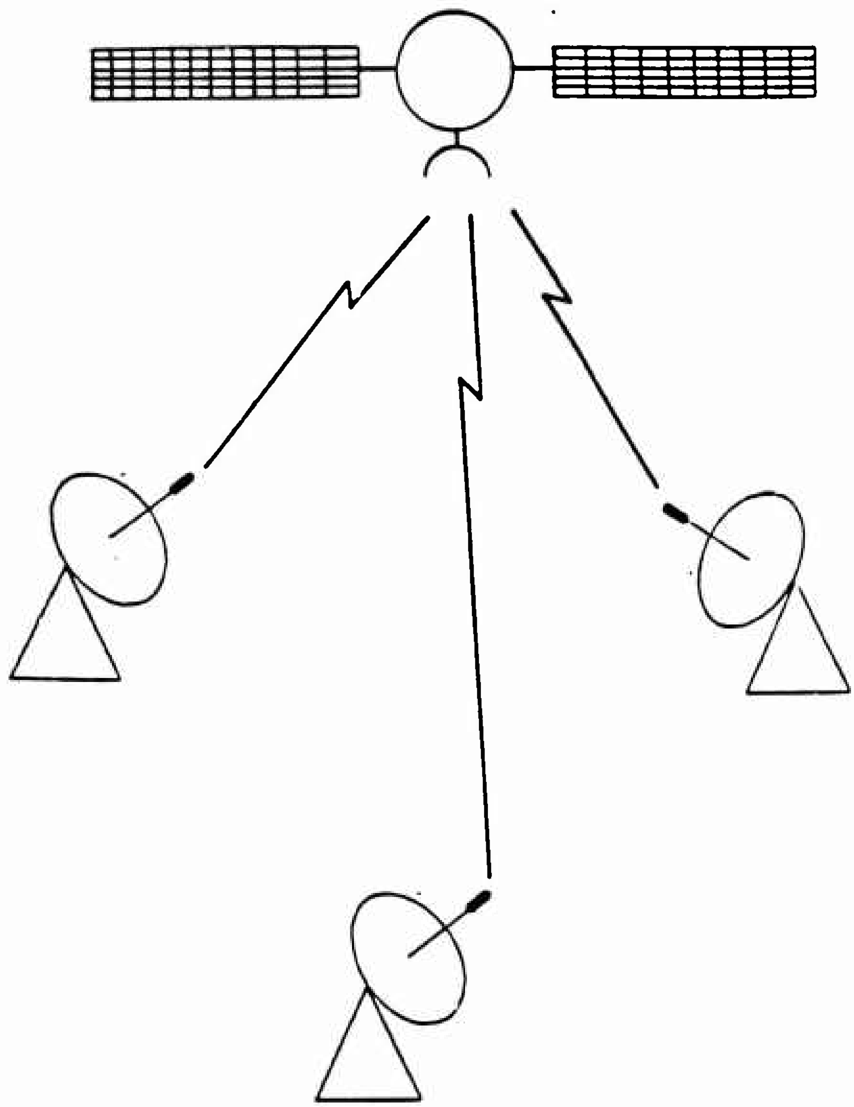


Fig. 1. A representative satellite communications system

The first use of a VSAT system was for one-way broadcast of information. This used technology similar to that used for direct broadcast of television signals to private users. It used small antennas connected to a small, low-cost receiver. An example of where this might be used is the stock market, sending periodic stock price updates to subscribers.

This has expanded to two-way communications, most notably between host computers and remote terminals. The satellite system replaces the modem and telephone line with a satellite transceiver. A virtual circuit is established between the terminal and the computer. Figure 2 shows a typical VSAT terminal/host computer network.

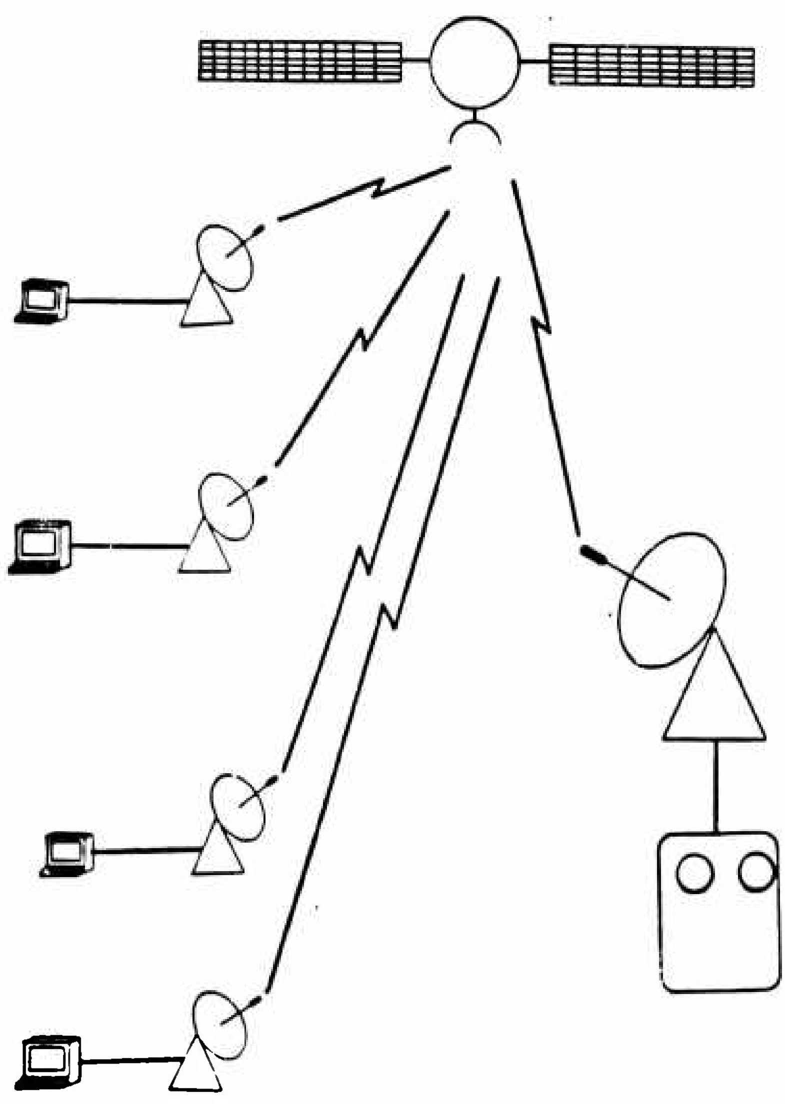


Figure 2. A typical VSAT Network

VSAT Characteristics

In describing a VSAT system, several characteristics must be addressed. Among them are system topology, frequency, and access method. In the following paragraphs, I will discuss each of these characteristics.

Topology

There are two main topologies used today in VSAT systems. The most prevalant topology is the star. As might be expected, the star topology has a central ground station, and all remotes talk directly (and exclusively) to it. The star topology works best when the network has many remotes communicating primarily with a single host processor, such as remote terminals accessing a central data base. Transmission rates usually reflect this. A central site may transmit at 56 KBS or more, while remotes may be transmitting at 9.6 KBS. Typically, the central earth station also acts as a network management site and is much larger than the remotes. Remote-to-remote communications are possible, through a double-hop transmission by way of the central site. Depending upon the application, bandwidths available, and size of the network, this arrangement may be feasible. For example, if the network is being used for small file transfers or short messages, the extra transmission delay (approximately 1/4 second in each direction) may not be noticed by the person using the terminal. (Note, however, that the computer equipment may notice this delay, and the protocol used must tolerate it. More on protocols in Section 2.). If the network is being used for critical interactive applications, users may not tolerate the extra delay. Figure 3 illustrates the star network.

The other main topology is the mesh. In a mesh network, all nodes are able to talk directly with all other nodes. A mesh network may be used for clustering host computers, when remotes primarily communicate with each other, or when there is a critical need for low response times. A distributed computing system would be a good candidate for a mesh network. Each of the earth stations will be larger than a remote station on a star network, but need not be as large as the central site. One of the sites will double as the network manager. Bandwidths on each of the legs will be equal or nearly so, unlike the large difference between incoming and outgoing legs of the star. Figure 4 illustrates the mesh network.

Combinations of these topologies are also common. It is not unusual to have a hybrid network, with star networks concentrating traffic destined for one or more hosts. The hosts are then connected via mesh network. A variety of combinations can be used to meet the specific needs of the user. Figure 5 illustrates a hybrid network.

Access Methods

For many users to share a limited resource, some scheme must be devised to provide orderly access to the satellite. The methods most commonly in use are frequency division multiple access, time division multiple access, code division multiple access, aloha, or some hybrid of these.

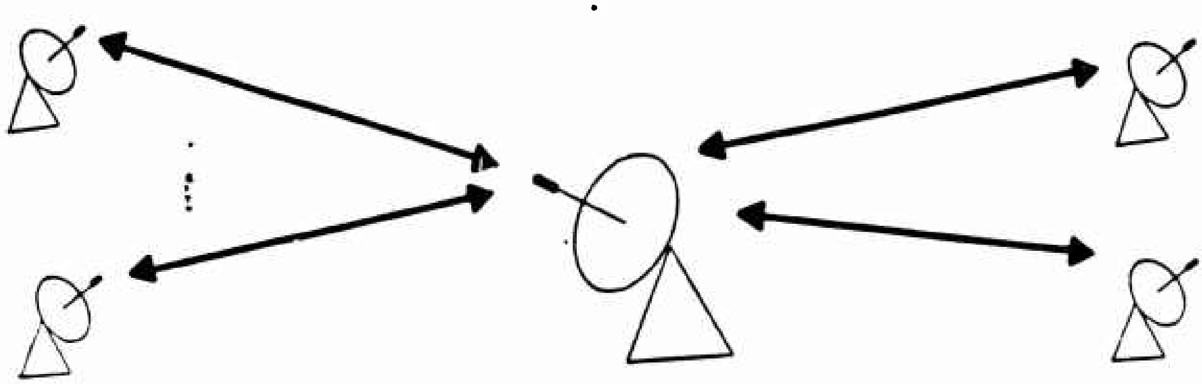


Figure 3. A star topology network.

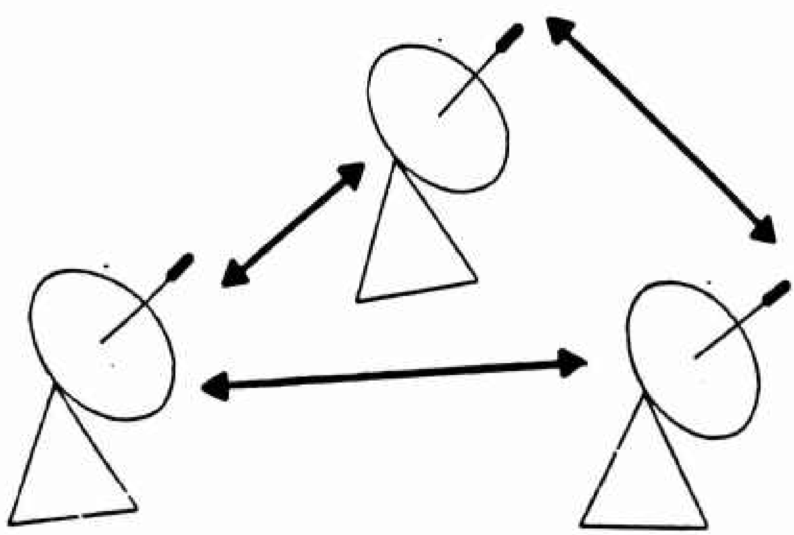


Figure 4. A mesh topology network.

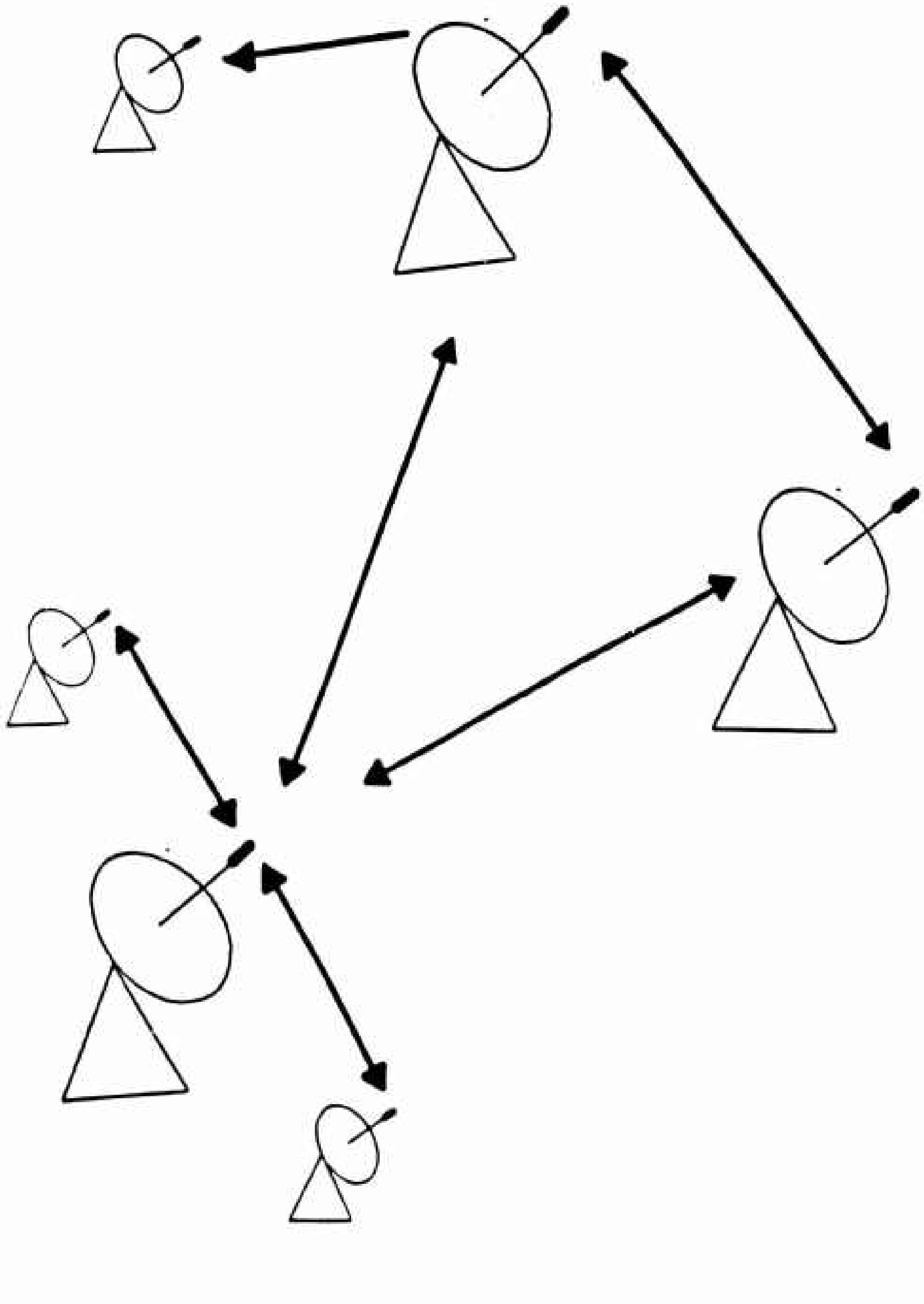


Figure 5. A hybrid topology network.

In frequency division multiple access (fdma), users are assigned individual subdivisions of the available bandwidth. The assignments need not be equal. Larger volume users may be assigned wider bandwidths than smaller users. Assignments can also be dynamic. If a particular user has a one time need for a high data rate, this can be provided, on a session basis.

Time division multiple access (tdma) is a similar scheme, but dividing the time rather than frequency. Users are assigned time slots to transmit. Timing signals from the master station maintain slot synchronization. Similar (to fdma) comments can be made with regard to high volume versus low volume users (longer versus shorter times) and dynamic slot assignment.

Code division multiple access (cdma) does not resemble either of the previous schemes. CDMA is a form of spread spectrum. The signal to be transmitted is mixed with a pseudo-random noise (PN) signal. This is a seemingly random (hence, the name) series of 1's and 0's. The effect is to spread the information signal to many times its original bandwidth, but at a lower power. This spreaded signal is transmitted through the satellite to the receiver. At the receiving end, the signal is mixed with the same PN signal used to spread it. The result is a de-spreading of the signal to its original form. Other signals received which have been spread by other PN signals are further spread, and are lost as noise. In this manner, several users can occupy the same bandwidth at the same time without interference. At some point, however, the sum of the spread signals (which appear as a noise component) can reach a level above which bit error rates are affected.

Aloha is an access method developed by the University of Hawaii for satellite communications. Users transmit whenever they have traffic to send. If a "collision" of signals (i.e., two users transmitting at the same time) is detected, each user backs off for a random time period and try again. The chances that the time periods will be the same is small. Priority can be established by weighting the random time period. Higher volume users can be given shorter "back off" times than low volume users. This access technique is best suited to systems of relatively low volume users. As the volume increases, collisions become more frequent, and system throughput can drop rapidly.

No single access method is best for all systems. Each has their advantages and disadvantages, and the task is to find the best method for the specific application. In some cases, a hybrid may be best. For example, you may have frequency division multiple access through the satellite, and have time division multiple access within each frequency subdivision. Another approach is to set up a reservation channel. When a user has traffic, he requests a session from network management. This channel can use one access method, such as aloha. He is then assigned a slot for the length of his session. This slot can be a frequency for fdma, a time for tdma, or a code for cdma. This attempts to combine the best features of the various methods to obtain maximum throughput. Each application is unique, and designers of VSAT systems must decide which access method or methods is best.

C-band vs. Ku-band

Another of the choices for VSAT designers/users is that between C-band and Ku-band. As with other choices, neither is best for all systems, and the choice must be based on the system at hand.

C-band is the 6/4 GHz pair. (Earth stations always transmit at the higher frequency of the pair.) One advantage to this frequency pair is that it is relatively immune to rain fade. Rain fade is a phenomena which occurs when the length of the radio wave approaches the size of a rain drop. When this happens, severe attenuation of the signal can be experienced. Another advantage (in the short term) is the lower price for hardware. C-band equipment is also used for terrestrial microwave systems, so there is an abundance of equipment. That abundance of equipment is also the biggest drawback to C-band. With the high use of the band for terrestrial microwave circuits, the potential for interference is equally high. Therefore, before C-band systems can be installed, more extensive site surveys must be completed to ensure no reasonable probability for interference. If interference is likely, it will be necessary to take some type of mitigating action. These actions include relocating the antenna behind buildings away from the other signal, constructing shields, relocating the earth station to a new site, etc. The most extreme avoidance action would be to not use VSAT at that site. Often, C-band antennas must be located on the ground rather than on a rooftop. Because of increased site preparation (concrete pad, trench for conduit, etc.), a ground mount is more expensive than a rooftop installation. Another disadvantage of C-band is also inherent in the frequency band. A larger antenna must be used to achieve the same beamwidth. Or put another way, the same size antenna will have a wider beamwidth. This means that to reduce adjacent satellite interference, some type of filtering or other action must be taken. This adds system complexity and cost.

Ku-band uses the 14/12 GHz pair. The higher frequency means that the same size antenna will produce a narrower beamwidth than at C-band. Beamwidths for 2° satellite spacing (2° difference in apparent longitude) are more easily achieved at Ku-band. Also, Ku-band is almost entirely devoted to satellite systems. Terrestrial interference is not a problem. Since it is not as common as C-band, Ku-band equipment is at present more expensive. As satellite systems proliferate, the price differential may be expected to drop. Ku-band's biggest disadvantage is rain fade. In areas of high rain, some measures may be necessary to overcome the increased attenuation. Note that the rain fade rarely, if ever, results in a lost signal. Rather, the attenuation is higher, and bit error rates may increase. There are charts available to predict probabilities of rain fade, and systems can be designed for theoretical 99.9% availability. Actions to overcome rain fade include increased power, slower data rates, using a larger antenna, etc.

2.0 Why VSAT?

Advantages

VSAT networks offer a number of advantages over terrestrial networks. First, they can cover a very wide area. Network coverage is the same as the satellite footprint. One satellite could provide coverage for CONUS, plus the possibility of spot beams to Alaska and/or Hawaii. Actual coverage is a function of the orbital position of the satellite.

Another advantage is the wide bandwidth available. Bandwidths of 56 KBS on up to 512 KBS are available, depending upon your need. If you choose to lease service (more on lease vs. purchase will be covered later), bandwidths can be tailored to fit individual network requirements.

VSAT networks can be lower cost than landline networks. This is highly dependent on the application; geographical areas involved, network size, terminal location and a number of other factors must be accounted for. However, some vendors are advertising rates on the order of $300-500 per month per site. Generally, this cost includes equipment, maintenance, network management and other costs associated with the service. This would not include any local circuits which may be necessary for terminal access. In addition, your cost is fixed and predictable. Long term leases or outright purchase or some combination of the two can fix the price over a five year or more period. This is contrasted with landlines, whose price will be expected to rise over the period by an unknown amount. Through the use of VSAT nets, the user is no longer at the mercy of state public utilities commissions and the FCC.

One of the biggest advantages VSAT networks can provide is system flexibility in the adding, dropping, or relocating terminals. Because (ideally) there are no telco circuits to install, and the satellite doesn't care which terminal is where, remote sites can be relocated almost at will. A typical installation time is about 20 minutes, if no site preparation is needed. Adding or dropping sites can be accomplished at the network management site. Reconfiguring an entire system can be done as quickly as it takes to physically move the equipment from one place to another.

Disadvantages

One of the biggest disadvantages of VSAT networks is the initial purchase, if that is the chosen route. Remote stations cost $6-20K each, and central hub earth stations can run $1M or more. Added to that is the space segment cost, which may only be available in discrete channel sizes that may or may not fit current and future needs. Leasing a transponder from a satellite operator can be on the order of $150K per year. When all costs are figured (equipment, installation, satellite transponder) the initial capital investment is likely to be in the millions of dollars. When these costs are amortized over a five-year period, the average cost per month may be low, but a sizeable investment is needed to get started.

In operation, satellite systems may suffer from increased response times. This is due to the fixed 45,000 mile path for each signal. In some applications, this will not be a problem. For others, it may be a fatal flaw. One mitigating factor is that the delay is a known constant, and can be designed into the network application.

Some protocols are not well suited for satellite transmission. Polling protocols are particularly ill-suited. One goal of a network manager is to maximize throughput in a system. Polling is overhead, and conveys no information. As the overhead fills the system, throughput drops. One may have a 56 KBS data rate through the network, and little information. Some vendors have gotten around the polling problem by having the central hub simulate responses to the host computer, and having the remote earth station simulate polls to the data terminal. This is cumbersome, but it frees the network to pass information. Protocols which reduce overhead, such as by increasing the frame length beyond that for landline protocols, provide the best performance over a satellite link.

3.0 Implementation Issues

Deciding to choose VSAT is perhaps the easiest one to make. Now that you have chosen that route, there are many other decisions that will not be as simple. Probably the first that should be made is lease vs. purchase.

There are several categories of expenses for a satellite network. Among them are initial hardware, installation, maintenance, network management and operations, and space segment use. These costs/functions must be paid for, whether directly (in the case of a totally owned and operated system) or indirectly (in the case of a totally leased system). Either alternative has its own advantages and disadvantages. The decision must be made after a careful economic analysis of a specific network. In this section, I will try to explain these costs and reasons for choosing to buy or lease.

The first category is hardware. Hardware includes the indoor and outdoor portions of the remote terminal and the cabling between them. Depending upon the transmission rates and quantities purchased, prices can vary from approximately $6K-20K per terminal. The obvious advantage to purchase is that once the terminal is paid for, there are no additional hardware charges. The disadvantage is that the owner is responsible for maintaining it, whether he uses his own people or contracts for it. Terminal ownership may provide more flexibility in making changes to the network.

Installation of the hardware can be nearly as expensive as buying the hardware, particularly for C-band systems. Larger antennas will require more stable mounts to resist pointing errors caused by the wind. Pointing errors of as little as 1° can at best increase the BER and at worst require a service call to re-aim the antenna. If a ground installation is required, either for interference mitigation or because rooftop mounting was not permitted, costs can be expected to be quite high. Before deciding to buy equipment, installation costs for each site should be examined. With any system, mounts which require penetration of the roof should be avoided. Once breached, membrane roofs are difficult repair, and replacement of the roof is quite expensive. Many building owners will not permit penetrating mounts; those that do will likely require that you assume liability for leaks.

Network management and operations is the largest single expense for a VSAT network. This includes the central node station and the people necessary to operate it. Depending on transmission rates, central ground station hardware can cost from $600K-2.0M. Additional funding would be necessary for installation and the people necessary to operate the central site. A larger portion of land will be needed for the antenna. Rooftop mounting is probably not practical for an 8-10 meter dish. If central site services are leased, then dedicated lines must be procured between the vendor's hub and the host computer site. That line could run across town, across the state or country, depending upon where the vendor has points of presence. Purchased central site networks are usually economically viable for larger networks (terminal population in the hundreds), where the cost of the central site can be amortized over a large number of remote sites.

The final category is the space segment. If the decision is to buy, then what you are buying is transponder capacity in whatever size bandwidth the vendor is offering. That "chunk" of bandwidth may or may not be well-suited for current and future growth needs. If you initially buy a lot more than is necessary you may waste money on unneeded capacity. On the other hand, if you buy too little, and network growth requires additional capacity, it may be expensive to buy another chunk. If VSAT service is leased, you probably will be able to lease only the capacity you need at the time. As needs grow, you generally will be able to incrementally add to your capacity.

If one decides to lease the entire service, costs vary from $300-500 per month per site, plus an initial installation cost per site. The monthly costs usually include all hardware, maintenance, network management and operations, and space segment charges. The cost does not include any lines necessary between the central site and the host computer, unless the vendor specifically is requested to provide that service. In that case, the central site cost will be larger to cover the line charges. In a leased service network, you lose some measure of flexibility, since any desired network changes would require a service change order to the vendor. In addition, you lose the network management freedom that may be enjoyed in a purchased system.

A hybrid system may be the most cost-effective alternative for Coast Guard use. In a hybrid system, we may find it economical to purchase and install remote terminals at specific locations, and lease central site capacity and network management functions. By using this alternative, we can keep our initial investment relatively low ($20K/site). We can take advantage of the economies of scale through a shared (leased) hub arrangement with a VSAT vendor. A hybrid may give us the relocation freedom of owning the remote terminals, yet avoid the high price of a central site. However, a cost analysis should be done for each alternative, be it wholly-owned, leased, or some combination of the two. A form similar to Figure 6 is suggested. This form was included in class notes from a seminar on VSAT networking presented by Mr. Philip Arst.

4.0 Summary

VSAT systems have been shown to be a viable alternative to dedicated leased lines. They can be less costly to operate and to reconfigure to meet changing needs. The potential savings must be calculated for specific configurations and applications.

There are many variables to consider when designing a VSAT system. Among them are the frequency band, access method, and topology. When purchasing or leasing a system, a good understanding of these is necessary, whether you specify them explicitly or set functional requirements for a vendor to meet. Each option has its advantages and disadvantages, and trade-off's are likely. The goal is to make well-founded decisions based upon the specific need.

VSAT systems are still a relatively new market. While the traditional large satellite systems companies have a presence, the market was created by a couple of smaller companies. Some have compared this market to the small computer market of a few years ago. At this point, it is difficult to predict which ones will make it in the long run. The best choice for the Coast Guard is to purchase remote site terminals and lease shared hub service from a VSAT vendor. This would allow us to take advantage of the technology at a low capital investment cost, yet still reduce our present costs for some dedicated circuit applications.

CONFIGURATION ______________________ DATE __/__/__

ITEM	QUANTITY (UNITS)	PURCHASE ($) UNIT	MONTHLY/UNIT @ 60 MO.	TOTAL FOR NETWORK
VSAT HARDWARE				
VSAT INSTALLATION				
VSAT FACILITIES PREP.				
VSAT MO. MAINT.				
SPARES				
SPACE SEGMENT CHGS				
SPACE SEGMENT BCKUP				
NETWORK SVC CHGS				
HOST LINK TO M.S.				
FEP PORTS/MODEMS				
PORTS/MODEMS MAINT.				
NET MGMT. CONSLE.				
MASTER STN R.F.HDW				
MS PROCESSORS,MISC.				
MS INSTALLATION				
MS MAINTENANCE				
MS FACILITIES				
MS OPERATION				
MOVES @ _____ %/YR.				
DOWNTIME				
OTHER				
TOTAL				

Fig. 6. Satellite Cost Analysis Form